

SIMULATION RESULTS OF A WIRELESS ECG-DERIVED RESPIRATION DEVICE

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Abstract- This paper reports on preliminary results of an ongoing research concerned with the sudden infant deaths syndrome. The aim of this research is to design and implement a PIC-microcontroller-based monitoring system for measuring ECG-derived respiration. The proposed system represents a radio telemetry system that provides the possibility of heart rate and respiratory signal transmission from a patient's detection circuit via an RF data link to a PC through NIDAQ or RS232 computer interface. Software that displays the respiratory signals and helps in its interpretation will also be used to save and send data by email to a desired location. Software Packages of MatLab, Orcad P-Spice, and PIC-Circuit for PIC code testing were used to simulate both analog and digital stages of the proposed system. Simulation results were validated against standard signals and showed promising potential. The results showed almost perfect match in terms of morphology, amplitude, and period (respiration rate).

Keywords - ECG Derived Respiration, Wireless Respiration monitoring, real time respiratory monitoring, PIC-Microcontroller, Sudden Infant Death Syndrome.

I. INTRODUCTION

The use of wireless systems for vital sign monitoring plays a very important role in health care especially in reducing the number of hospitalizations and life saving. Real-time and continuous monitoring manner of biological signs speeds up the medical response to the person in need. In addition to ECG and blood pressure monitoring, respiration data represent the third vital sign of importance. Disorders of respiratory tract are among the most important and serious conditions that can affect the patient's health.

Despite the great advances in medicine and medical technology the Sudden Infant Death Syndrome (SIDS) continues to represent a grave problem of medical significance. It is believed that SIDS is primarily related, among other factors, to respiration problems associated with the immature and developing brain breathing control [1]. Heart rate and respiration monitoring in this regard is considered of major value at home in particular [2]. The outcome of this monitoring is to detect heart rate below a limit between 80 and 100 beats/min and apnea.

One of the methods used to obtain respiratory information indirectly from the ECG signal is the ECG-derived respiration (EDR). This is especially important when the ECG, not the respiration, is routinely monitored. One can perform respiratory signal extractions by some signal processing approaches. Furthermore, obstructive apnea and changes in the patient's tidal volume are also clearly recognizable in EDR. Several efforts by Moody et al. (1985); Moody et al. (1986); Lipsitz et al. (1995); Nazeran et al. (1998) and Behbehani et al. (2002) have been put for such a purpose [3]. The main idea of the EDR method stems from the fact that the ECG signal recorded from the surface of the subject's chest is influenced by electrodes motion with

respect to the heart and by changes in the electrical impedance of the thoracic cavity. The expansion and contraction of the chest, which accompanies respiration, results in motion of chest electrodes; meaning that respiration acts as a modulation on the ECG source that appears as amplitude variations in the observed ECG [2,4].

Morphology changes in the ECG signal due to respiration give the possibility of deriving a signal proportional to the respiratory movement on a beat-by-beat basis [5]. Typically, this respiratory signal is derived by computing the ratio of the areas of QRS complexes in two different leads. This technique was validated with data derived from sleep apnea studies and Cheynes-Stokes patients, and applied to study breathing at high altitude and during chronic congestive heart failure. A different approach is based on the assessment of direction changes of successive vectorcardiogram (VCG) loops. Respiration information could also be extracted from the ECG based on the changes in the difference between the peaks of the R- and S-waves over time. The peaks of the R- and S-waves change because the potential between the two points (where electrodes are placed) varies when the chest cavity expands or contracts during respiration. When a person inhales, the distance between the two electrodes increases, thereby increasing the skin resistance, the result is a larger potential difference; the opposite holds true during expiration. Therefore, plotting the difference in peak voltages versus time will result in a sinusoidal signal that represents a person's respiration pattern.

One may ask, why going for the ECG-derived respiration alternative and not to use direct measurement of respiration such as the total body plethysmography (TBP), strain gage measurement of thoracic circumference, and mouth air flow detection by thermistor, which would give more accurate results. The answer is quite simple; the EDR method uses the same ECG electrodes and their relative artifact immunity and does not require immobilization of the patient as in the TBP case. It also avoids the use of high frequency currents and frequent recalibration of transducers [1].

Based on the arguments presented above, this study was initiated with the aim of designing and implementing a device that will continuously monitor the heart rate and the ECG-derived respiration. The device includes an ECG detection circuit, a PIC 16F877 micro-processor, and a transceiver. Another transceiver located in a remote center will receive the data via RF link. An algorithm written for this purpose will process data and display them. PIC microcontroller will cause alarm if either of the vital signs falls within an unacceptable range.

II. THE SYSTEM DESCRIPTION

The proposed system in this study consists of a transmitting unit (patient unit) and a receiving unit (PC Unit).

The block diagram of the proposed system is shown in Figure 1.

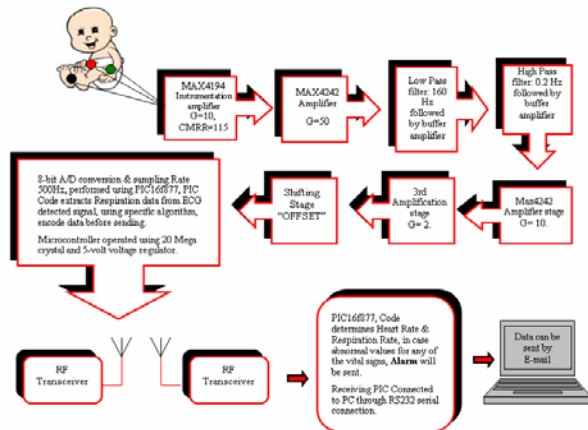


Fig. 1. The block diagram of the ECG-derived respiration device.

A. Patient Unit-ECG detection Hardware.

The amplitude of the infant ECG signal ranges approximately from $80 \mu\text{V}$ to 2 mV and the heart rate range is 120 to 160 beats/min [6]. The acceptable range for respiration is 25 to 40 breaths/min meaning that the breathing frequency varies from 0.67 up to 50 Hz. The specific design procedures used for signal analysis and conditioning are as follows:

1. Amplification: The differential amplifier Max4194 with a CMMR $> 110 \text{ dB}$ is used to amplify the detected signal from the two electrodes placed on the infant's chest. Since the gain needed for effective ECG measurements is 50000, three stages of Max4242 amplifiers were added [7].
2. Filtration: The ECG signal detected contains several kinds of noise such as the low-frequency noise produced by respiration, electrode movement that results in a base line drift, and the power line interference. To adequately remove these noises, a low-pass filter with a cutoff frequency of 160 Hz, high-pass filter with cutoff frequency of 0.2 Hz, and a notch filter are used. Passive filter design was preferred here over the filter design containing active components since the former generates less noise. In addition, it requires no power supply which is a crucial issue for wireless systems.
3. ECG-shifting circuit: A circuit in a form of summing amplifier was used to shift the ECG signal upward thereby ensuring that all the signal parts will be included since the PIC microcontroller can work only with positive values.
4. PIC 16F877A microcontroller: The software written for the PIC microcontroller includes signal encoding/decoding communication protocols.
 - a) Transmitting PIC: The PIC microcontroller uses a 10-bit ADC and a 500-Hz sampling frequency. The proposed algorithm extracts respiration information from the detected and processed ECG data according to the flowchart shown in figure 2.

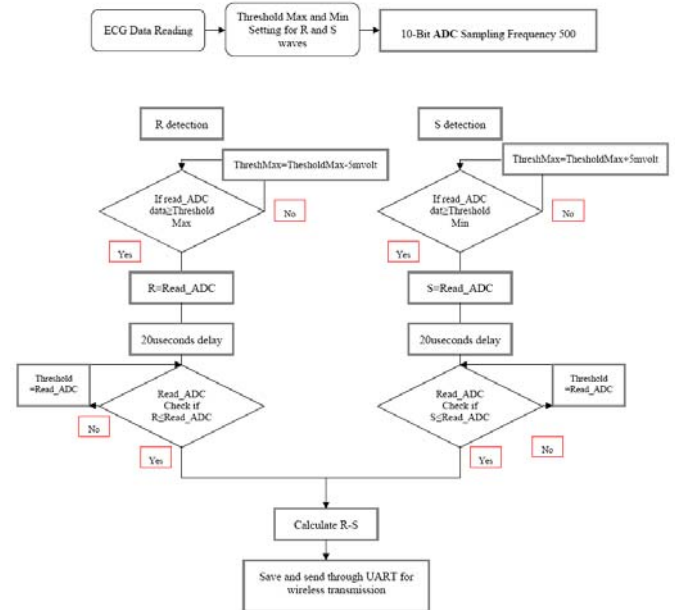


Fig. 2. The flowchart of the algorithm written for the transmitting PIC microcontroller.

The PIC first begins data reading and sets the threshold maximum and minimum values for R and S detection. To overcome the problem of patient's movements, threshold values are searched adaptively. For a 10-bit conversion this can be solved by setting threshold for R to its maximum value that ranges from 1023 to 512 (4.8 to 2.4V) and for S to its minimum value that ranges from 0 to 207 (0 to 1V). The R detection is performed as follows: once the timer is turned on, PIC begins to compare data samples with the set threshold value. If the sample is greater or equal to the threshold, then R is equal to the sample. Otherwise the threshold value is decreased by $(5/2^{10})$ and comparison is applied again. The PIC continues to search for R wave till a decremented value less than 2.5 V for the threshold is reached. Values less than this are considered noise and the timer resets to begin another search. To ensure a precise R value detection, a delay of $20 \mu\text{s}$ is applied and its corresponding value (new R value) is compared with the threshold. If R is less or equal to the threshold the R considered previously is cancelled and search starts again.

The same procedure used for R detection is also applied for S detection except that the threshold value is incremented. As the R and S values for each heart beat are found, PIC calculates the difference between them. The heart rate and respiration are then calculated and data are serially transferred to USART for wireless transmission.

- b) Receiving PIC: The flowchart of the receiving code is shown in figure 3. The PIC reads the received data from the RF receiver through R_X pin on the PIC. The data will be sent to the data acquisition device (NIDQ card) the output of which is fed through the parallel port to the PC. Finally, the signal will be displayed on a PC by using Matlab program designed for this purpose.

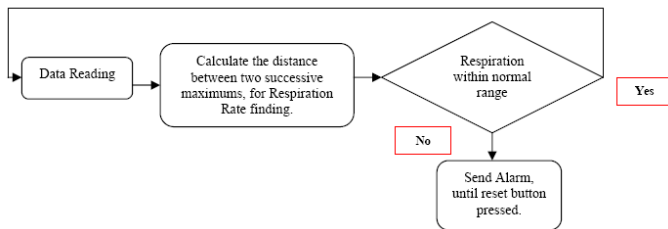


Fig. 3. The flowchart of the receiving PIC microcontroller.

II. METHODOLOGY

It should be clarified here that in this ongoing research, the main effort lied in making sure that the analog circuit design, the algorithms, and the PIC circuit connections were functioning properly. The following paragraphs elaborate on the major components of the proposed system as to their method of operation.

A. The analog circuit testing

The analog circuit comprises signal amplification, filtration, and shifting (fig. 1). All these parts were simulated using the P-Spice Orcad software package. As an integral and necessary component of this part, an ECG circuit simulator had to be designed within the P-Spice Orcad for testing purposes.

B. The PIC testing

The testing of this part involves verifying the validity of the algorithm (software) and that of the PIC connections (hardware). As it was not possible to test it directly in this phase of the study, the algorithm was verified by writing an identical code to that of the PIC in a manner that is compatible to MatLab and was tested in MatLab. As for the PIC connections, they were tested using a PIC Kit with 8 MHz crystal. The input data for the PIC Kit were generated using a potentiometer to meet the characteristic features of the standard ECG signal.

III. RESULTS AND DISCUSSION

The simulation results of this study are shown in figures 4 through 6. Figure 4 shows a sample amplified and filtered ECG signal generated by the ECG simulator. The output shows an evidence of the successful design of the analog part of the system. Figure 5 shows an ECG signal (upper portion) of a 2-day old infant that was input to the MatLab code along with the respiratory signal (lower portion) generated from the corresponding ECG signal. The output indicates an excellent match in morphology, amplitude, and respiratory rate.



Fig. 4. A sample of an amplified and filtered ECG signal generated by the ECG simulator

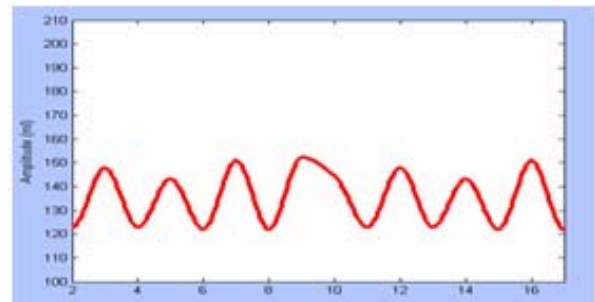


Fig. 5. An ECG signal (upper portion) of a 2-day old infant that was input to the MatLab code along with the respiratory signal (lower portion) generated from the corresponding ECG signal

Figure 6 shows a sample results obtained during the PIC testing using the PIC kit



Fig. 6. Results obtained during the PIC testing

V. CONCLUSION

The results of this part of the study indicate a promising potential for the proposed system to be further implemented as a hardware device.

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